The Comprehensive Complication Index (CCI®) is a Novel Cost Assessment Tool for Surgical Procedures

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Abstract: OBJECTIVE The aim of this study was to identify a readily available, reproducible, and internationally applicable cost assessment tool for surgical procedures. SUMMARY OF BACKGROUND DATA Strong economic pressure exists worldwide to slow down the rising of health care costs. Postoperative morbidity significantly impacts on cost in surgical patients. The comprehensive complication index (CCI), reflecting overall postoperative morbidity, may therefore serve as a new marker for cost. METHODS Postoperative complications and total costs from a single tertiary center were prospectively collected (2014 to 2016) up to 3 months after surgery for a variety of abdominal procedures (n = 1388). CCI was used to quantify overall postoperative morbidity. Pearson correlation coefficient (rpears) was calculated for cost and CCI. For cost prediction, a linear regression model based on CCI, age, and type of surgery was developed and validated in an international cohort of patients. RESULTS We found a high correlation between CCI and overall cost (rpears = 0.75) with the strongest correlation for more complex procedures. The prediction model performed very well (R = 0.82); each 10-point increase in CCI corresponded to a 14% increase to the baseline cost. Additional 12% of baseline cost must be added for patients older than 50 years, or 24% for those over 70 years. The validation cohorts showed a good match of predicted and observed cost. CONCLUSION Overall postoperative morbidity correlates highly with cost. The CCI together with the type of surgery and patient age is a novel and reliable predictor of expenses in surgical patients. This finding may enable objective cost comparisons among centers, procedures, or over time obviating the need to look at complex country-specific cost calculations (www.assessurgery.com).

DOI: https://doi.org/10.1097/SLA.0000000000002902

Originally published at:
Staiger, Roxane D; Cimino, Matteo; Javed, Ammar; Biondo, Sebastiano; Fondevila, Constantino; Périnel, Julie; Aragão, Ana Carolina; Torzilli, Guido; Wolfgang, Christopher; Adham, Mustapha; Pinto-Marques, Hugo; Dutkowski, Philipp; Puhan, Milo A; Clavien, Pierre-Alain (2018). The Comprehensive Complication Index (CCI®) is a Novel Cost Assessment Tool for Surgical Procedures. Annals of Surgery, 268(5):784-791.
DOI: https://doi.org/10.1097/SLA.0000000000002902

The Comprehensive Complication Index (CCI®) is a Novel Cost Assessment Tool for Surgical Procedures

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Objective: The aim of this study was to identify a readily available, reproducible, and internationally applicable cost assessment tool for surgical procedures.

Summary of Background Data: Strong economic pressure exists worldwide to slow down the rising of health care costs. Postoperative morbidity significantly impacts on cost in surgical patients. The comprehensive complication index (CCI®), reflecting overall postoperative morbidity, may therefore serve as a new marker for cost.

Methods: Postoperative complications and total costs from a single tertiary center were prospectively collected (2014 to 2016) up to 3 months after surgery for a variety of abdominal procedures (n = 1388). CCI® was used to quantify overall postoperative morbidity. Pearson correlation coefficient (r_{pears}) was calculated for cost and CCI®. For cost prediction, a linear regression model based on CCI®, age, and type of surgery was developed and validated in an international cohort of patients.

Results: We found a high correlation between CCI® and overall cost ($r_{pears} = 0.75$) with the strongest correlation for more complex procedures. The prediction model performed very well ($R^2 = 0.82$); each 10-point increase in CCI® corresponded to a 14% increase to the baseline cost. Additional 12% of baseline cost must be added for patients older than 50 years, or 24% for those over 70 years. The validation cohorts showed a good match of predicted and observed cost.

Conclusion: Overall postoperative morbidity correlates highly with cost. The CCI® together with the type of surgery and patient age is a novel and reliable predictor of expenses in surgical patients. This finding may enable objective cost comparisons among centers, procedures, or over time obviating the need to look at complex country-specific cost calculations (*www.assessurgery.com*).

Keywords: CCI®, complications, cost, morbidity, surgery

(*Ann Surg* 2018;268:784–791)

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This study is supported by LGID (Liver and Gastrointestinal Disease) Foundation, Zurich, Switzerland and the Clinical Research and Priority Program ''Liver tumors'' from the University of Zurich, Switzerland (to P.-A. Clavien).

R.D. Staiger is a recipient of a grant/research funding from the Olga Mayenfish Foundation, Zurich, Switzerland.

The authors have no conflicts of interest.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (www.annalsofsurgery.com).

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ISSN: 0003-4932/18/26805-0784

DOI: 10.1097/SLA.0000000000002902

Health care costs are consistently rising worldwide, implicating economic threats in many countries.[1] Great variations in health care cost exist among countries ranging from 5.1% gross domestic product (GDP) in Romania to 18.3% GDP in the United States.[2,3] Currently, no reliable and internationally applicable method is available for cost assessment in surgical patients.

Postoperative complications are known to be the most influential catalyzer of costs.[4–6] While the assessment of complications is still widely inconsistent, cost evaluation and comparison appear even more difficult. The comprehensive complication index (CCI®)[7,8] captures overall postoperative morbidity by severity, based on a prior ranking by the Clavien Dindo system.[9] This system, based on the resources needed to treat any single complication, is currently the most widely used grading of individual complications in many surgical fields.[7,10] The CCI® is a validated metric for postoperative morbidity ranging from 0 (no complication) to 100 (death), which was developed on the basis of patient and physician perspectives.[7,11] We hypothesize that assessing CCI® may concomitantly best inform about the total cost of a procedure, as it allows to trace cumulative progression of postoperative morbidity over time. This approach builds on the previous observation that already the most severe postoperative complication alone was found to correlate well with the procedure cost.[4]

Our aim was, therefore, to test the value of CCI® as a marker of cost after general and complex abdominal surgical procedures in a single tertiary center, and validate the predictive model in subsequent cohort of patients from the study center, as well as in an international, multicentric cohort of surgical patients.

METHODS

Study Design and Population

From a prospectively maintained database, we created 3 cohorts of patients undergoing general and complex abdominal surgery and followed them for up to 3 months after surgery. The first cohort consisted of patients from the Department of Surgery and Transplantation at the University Hospital Zurich, Switzerland, who received in 2014 or 2015 cholecystectomy; colon or rectum resections; liver, pancreas, bariatric surgeries, or liver transplantation (LT). This cohort served to develop the tool for cost prediction. The second cohort, used for a first, temporal validation of the cost prediction tool, consisted of patients undergoing these procedures in 2016. The third cohort, used for the second, external validation, consisted of patients from 6 international tertiary centers across Europe and the USA, who received surgery between 2014 and 2016. The selection of internal centers was based on available prospective data at the respective centers. Data on pancreas surgery were provided from the University Hospital of Lyon, France, and the Johns Hopkins School of Medicine, Baltimore, MD. For liver surgery, cases were added from the Humanitas Hospital, Milan, Italy, the Hepato-Biliary-Pancreatic and Transplantation Centre, Curry Cabral Hospital, Lisbon, Portugal, and the Hospital Clinic de Barcelona, Spain (2004 to 2014). Colon and rectum surgery data were provided by the Bellvitge University Hospital, Barcelona, Spain.

For each cohort, exclusion criteria were emergency surgeries, robotic resections, and incidental resections. Surgery-specific inclusion and exclusion criteria are provided in the Supplemental-Digital-Content 1, http://links.lww.com/SLA/B442. In case of combined surgeries, the more severe operation defined group allocation.

Measurements

All the studied patients of the Zurich cohorts were included in prospective databases held by the respective sections of the Department of Surgery. Complications and their treatment were gathered from medical records, laboratory results, and doctor's reports. The CCI® is the standard metric at the University Hospital Zurich for overall postoperative morbidity.[7,8] Each complication, graded by Clavien Dindo classification,[9] is recorded in the database and the CCI® was calculated accordingly by an online calculator (http://www.cci.assessurgery.com).

The 3-month follow-up was chosen on the basis of recent benchmark studies indicating that collection of data until discharge only is inaccurate, and that most postoperative complications occur within 3 months of surgery.[12] For the international validation, the same procedures were followed. However, cost data after discharge were not available in each center due to the different ways postoperative follow-up is organized. The validation of cost prediction was conducted according to the available data.

Cost Assessment

For the University Hospital Zurich, the costs, and not the charge, were calculated using the SAP system (SAP, Business Warehouse, Walldorf, Germany),[13] compliant to the standardized cost accounting guidelines of the association of Swiss hospitals (REKOLE).[14] For full cost analysis, complete in-hospital and outpatient expenses, including variable and fixed costs, were calculated from hospital admission to up to the completion of the 3 months observation period. The additional fees paid to doctors for private insured patients were ignored. After discharged, cost caused by any treatments or readmission was obtained again from the hospital administration. For the international validation, each of the participating centers also obtained the total costs without additional fees or charges from their respective hospital administration (Supplemental-Digital-Content 2, http://links.lww.com/SLA/B442). Cost accounting was conducted according to the country-specific standards.

Statistical Analysis

The correlation assessment of overall postoperative morbidity and total costs was calculated using the Pearson correlation coefficient (r_{pears}) for both the Zurich and the international cohorts. Referred reference values for strength of effect size were "very weak" 0.00 to 0.19, "weak" 0.20 to 0.39, "moderate" 0.40 to 0.59, "strong" 0.60 to 0.79, and "very strong" 0.80 to 1.0.[15] Due to the skewedness of the data, the natural logarithm (ln) transformation of costs was used. CCI® data are presented as medians and interquartile range (IQR).

To develop the cost prediction tool, a linear regression model was fitted to the 2014 to 2015 data from Zurich (development cohort) that included the CCI®, as well as 2 other easily accessible parameters: patient's age and type of performed surgery. The choice of the 2 additional parameters is based on the previous findings that costs of similar complications vary between different types of surgery.[4] Parameters for comorbidity assessment, such as the commonly used ASA classification[16] or Charlson Comorbidity Index,[17] were deliberately reframed from, as there are no precise measures of comorbidity or their severity. In addition, both have been determined to be inferior to complications regarding cost prediction.[4] Further, comorbidities are approximated well by the age of the patients and the type of surgery performed. With increasing age, the number and severity of comorbidities increase. Type of surgery also gives some indication of possible comorbidities (eg, bariatric surgery: common comorbidities are diabetes and high blood pressure). With the aim to keep this cost assessment method simple, we chose the easy assessable information age and surgery type, as no further grading is necessary.

To validate the cost prediction tool, we first predicted the cost, based on the model developed in the Zurich 2014 to 2015 cohort, for the Zurich patients from 2016 (temporal validation). Correlation of predicted and observed costs was calculated by Pearson correlation coefficient. Agreement of the 2 methods (prediction and observation) was assessed by Bland-Altman plot and conditional quantile. We then repeated this validation in the international cohort with patients from 5 European and 1 northern American country. For all statistical analyses, the program R was used.[18]

RESULTS

Characteristics of the Zurich and International Cohorts

In the 2 Zurich cohorts, a total of 1388 patients were included in the analysis: 357 of those received cholecystectomies; 134 colon, 107 rectum, 168 liver, 74 pancreas, and 408 bariatric surgeries. Finally, 140 patients received LT (Table 1).

International centers provided a total of 767 patients for the validation part of the study, including 292 patients for pancreas surgery (Lyon 48 patients and Baltimore 244 patients); 373 patients for liver surgery (Milan 285, Lisbon 36, Barcelona 52); and 56 patients for colon resections and 46 patients for rectum resections (Barcelona). Data were collected up to 3 months similar to the study population, except for 4 centers (Lisbon, Lyon, Barcelona, Baltimore), which could only accurately provide in-hospital cost data. For these latter procedures, comparisons were done only with the CCI® and related cost during the hospital stay.

Correlation Between Morbidity and Costs in the Zurich Cohort

A strong correlation between CCI® and costs was found up to 3 months postoperatively ($r_{pears} = 0.70$) (Fig. 1). This correlation was highest for the inpatient period ($r_{pears} = 0.75$), while focusing only on the postoperative course after discharge resulted in a weaker correlation of CCI® and cost ($r_{pears} = 0.33$).

Analysis According to Surgical Procedures

Further, we assessed CCI®/cost correlation of each type of procedure. Of note, correlation in the surgical group increased with higher morbidity, implying that the most complex procedures disclosed the highest correlation of CCI® and cost (Fig. 2, Table 1). For example, this is demonstrated comparing pancreas surgery

TABLE 1. Overview of Both Cohorts

(a) Zurich Cohort

Group (Total no.)	Median Age, y	Median Length of Hospitalization, d	No. of Complications up to 3 mo (% Occurred in Hospital)	Median CCI® 3 mo (IQR)	Median CCI® Hospitalization (IQR)	Median Cost US $ (to Discharge)	r_{pears} to 3 mo Postop	r_{pears} to Discharge
All (1388)	53.4	10	2497 (56%)	8.7 (29.6)	0 (20.9)	22,059 (20,668)	0.70	0.74
Cholecystectomy (357)	53.3	4	212 (39%)	0 (8.7)	0 (0)	9,904 (9,324)	0.39	0.39
Colon resection (134)	65.4	11	236 (73%)	15.0 (24.2)	8.7 (20.9)	27,239 (23,538)	0.77	0.65
Rectum resections (107)	61.5	14	245 (52%)	17.3 (22.7)	4.4 (20.9)	34,105 (28,894)	0.70	0.83
Liver surgery (168)	60.2	12	342 (57%)	13.6 (31.1)	8.7 (22.6)	34,322 (31,459)	0.76	0.80
Pancreas surgery (74)	61.5	19	274 (59%)	30.5 (34.2)	20.9 (38.2)	60,159 (50,004)	0.85	0.90
Bariatric surgery (408)	43.0	6	465 (27%)	8.7 (26.2)	0 (0)	20,544 (19,656)	0.28	0.46
Liver transplant (140)	54.2	25	723 (73%)	49.6 (39.9)	40.2 (38.2)	136,369 (127,691)	0.66	0.64

(b) International Cohort

Group (Total no.), Center	Median Age, y	Median Length of Hospitalization, d	No. of Complications up to 3 mo (% Occurred in Hospital)	Median CCI® 3 mo (IQR)	Median CCI® Hospitalization (IQR)	Median Cost US $ (to Discharge)	r_{pears} up to 3 mo Postop	r_{pears} up to Discharge
All (523)	62.2	13	295 (88%)	0 (20.9)	0 (22.6)	11,387 (18,143)	0.60	0.53
Liver surgeries (285)*	63.7	13	186 (91%)	0 (20.9)	0 (20.9)	11,098 (10,770)	0.55	0.55
Colon resections (56)†	69.0	10	32 (88%)	0 (20.9)	0 (20.9)	9,867 (8,319)	0.75	0.70
Rectum resections (46)†	66.5	14	41 (88%)	8.7 (29.6)	8.7 (20.9)	13,456 (11,397)	0.75	0.63
Pancreas surgery (244)‡	64.7	11	–	–	8.7 (22.6)	– (50,074)	–	0.66
Liver surgery (52)§	35.4	11	–	–	20.9 (22.1)	– (20,587)	–	0.53
Pancreas surgeries (48)¶	65.0	24	–	–	0 (20.9)	– (27,406)	–	0.83
Liver surgeries (36)‖	60.1	10	–	–	33.5 (24.5)	– (54,384)	–	0.60

a Zurich cohort: Median age, median length of hospitalization, number and severity of complications occurred overall and within the different surgical groups up to 3 months and hospital discharge. Respective median costs in US dollars up to 3 months and hospital discharge. Correlation between cost and overall morbidity calculated by Pearson correlation coefficient (r_{pears}) using natural log transformation of costs.

b International cohort: Median age, median length of hospitalization, number and severity of complications occurred overall and within the different surgical groups up to 3 months and hospital discharge. Respective median costs in US dollars up to 3 months and hospital discharge. Correlation between cost and overall morbidity calculated by Pearson correlation coefficient (r_{pears}) using natural log transformation of costs. For center 3–6, only in-hospital cost data available.

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CCI® indicates Comprehensive Complication Index; IQR, interquartile range; r_{pears}, Pearson correlation correlation coefficient.

($r_{pears} = 0.85$) to bariatric surgery ($r_{pears} = 0.28$). In contrast to the complexity of the surgery, LT displayed a relatively weak correlation ($r_{pears} = 0.66$). The surgical groups with weak correlation did not significantly influence the overall correlation strength.

Development of the Cost Prediction Tool

The linear regression model predicted cost very well ($R^2 = 0.82$) (Supplemental-Digital-Content 3, http://links.lww.com/SLA/B442). Each predictor was associated highly significantly with cost in the multivariable model (individual value of each predictor: surgery type R^2 0.71, CCI® R^2 0.51, age R^2 0.06). We found a 14% cost increase per 10 points of CCI® increase during the first 3 months. Of note, the cost increase was 20% when considering only the in-hospital period. Age had a significant influence on the weight of complications on overall cost. For patients older than 50 years, an extra 12% basic cost is added 1 time, independent of the CCI®. This figure is 24% for patients older than 70 years.

Validations

Two different methods of validation were applied. The first validation was performed in patients from the study institution in Zurich, in which the prediction model, compiled from the 2014 to 2015 period, was tested on the 2016 data. This displayed a good match of the predicted and observed cost (Figs. 3A, B, Supplemental Digital Content 4, http://links.lww.com/SLA/B442). The comparison of predicted and observed costs not only displayed a straight line but also matched in absolute terms (Figs. 3A, B). The Bland-Altman plot shows that, on average, there is no difference between predicted and observed cost while displaying a moderate spread (Supplemental-Digital-Content 4, http://links.lww.com/SLA/B442). The international validation supported the findings. In the comparison of predicted and observed costs, the results were located on a straight line, however, parallel running to the perfect fit, showing a 27.8% overestimation of costs (Figs. 3C, D). This was further shown by the Bland-Altman plot, displaying a 1.3 deviation in difference of the natural log of observed to predicted cost (Supplemental Digital Content 4, http://links.lww.com/SLA/B442). The international validation data further confirmed the good correlation of overall morbidity and cost ($r_{pears} = 0.60$) with a minor decrease of strength for the hospitalization period ($r_{pears} = 0.53$) (Table 1).

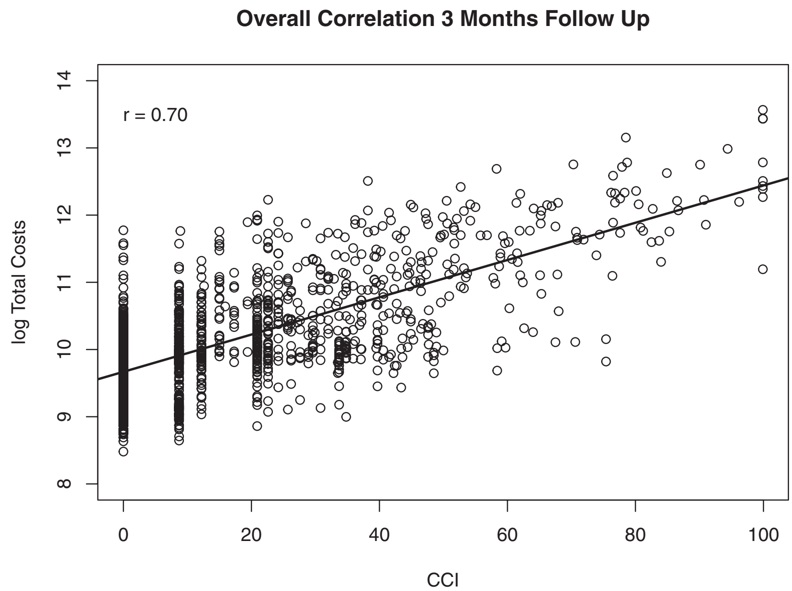

FIGURE 1. Correlation of CCI® and log of total costs of all 7 Zurich surgical groups combined at 3 months postoperatively. Pearson correlation coefficient (r_{pears}).

DISCUSSION

Assessing and restraining costs, while maintaining quality, is currently one of the most relevant challenges in medicine. A simple and validated marker of total cost of surgical procedures would be of great value, particularly if applicable in different health care systems. We present here the first evidence that overall postoperative morbidity provides an excellent marker of cost for abdominal surgical procedures. The validation studies in an international group of patients suggest that the predictive model offers wide applicability for cost assessment. From this inaugural study, linking postoperative morbidity with overall cost of a procedures, we would like to highlight 3 main observations.

First, the more complex the surgery, the stronger is the correlation between overall morbidity and costs. Second, the more meticulous and controlled the assessment of every complication, the stronger the correlation, indicating the great importance to objectively and fully register each complication. Third, cost in surgery are predictable when using the easily accessible metric system CCI®, patient age, and surgery type.

Surgical complications are the strongest driver of cost with the highest savings potential.[4] Importantly, severity, much more than the type of complications, determines cost accumulation.[4] Intending to capture every postoperative complication, the CCI® is therefore, a more precise measure of morbidity than the recording of single complications, typically with a focus limited to the most severe ones. Furthermore, CCI® encompasses the dimension of time into the calculation, as additional complications during the further postoperative course can easily be cumulated to the previous assessed values. Thus, meticulous, standardized tracking of postsurgical complications is the basis to accurately predict costs. Every treatment increases costs; thus, an incomplete complication assessment would moderate the accuracy of predicting cost.

CCI®, like cost, increases by the severity and the number of complications.[7,8] Surgeries with a higher occurrence of serious complications showed higher correlation between complications and cost compared with simpler procedures. This finding is demonstrated by the highest correlation for complex surgeries, such as pancreas, liver, or rectum resections. In contrast, LT showed a lower correlation of CCI®/cost despite being the most complex procedure. This is likely due to the sensitivity of the correlation coefficient to severe outliers, such as patients with high CCI® but surprisingly low cost (Supplemental-Digital-Content 5, http://links.lww.com/SLA/B442).

On the basis of these results, we advocate the CCI® as a credible marker of cost due to the strong correlation of overall morbidity and surgical case-costs. By adding surgery type and patient's age as surrogate parameters of surgical variations and patients' comorbidities, we developed and validated a cost prediction model. The model indicates that, considering a 3-month follow-up, for each raise of 10 points, CCI® cost incrementally increased by 14% of the baseline value. Interestingly, patient age had an additional influence on cost increase. Another 12% of the baseline cost must be added once, independent of the level of CCI®, for patient older than 50 years of age, and 24% for those over 70 years. For example, a 60-year-old-patient who underwent an abdominal procedure with a baseline cost of \$50,000. Her CCI® at 3 months after surgery was 50, which equals in total cost of \$91,000 [\$50,000 (baseline)+ \$35,000 (CCI® 50)+ \$6000 (age > 50 years)]. Further examples are presented in the Supplemental-Digital-Content 6, http://links.lww.com/SLA/B442. In addition, we offer an online cost assessment tool (www.assessurgery.com).

Hence, only knowing the basic cost of a procedure, an estimate of total costs can be calculated. This novel method enables a cost assessment independent of country-specific pricing-power, wages, costs of drugs and medical devices, and outside of hospital administrations; burdensome, time delayed ascertainment of cost data can be bypassed and inconsistencies in their calculations prevented. The difficulty to collect all costs is shown in the parallel deviation of predicted to observed costs in the international validation data (Figs. 3C, D, Supplemental-Digital-Content 4, http://links.lww.com/SLA/B442). The symmetry of this deviation illustrates not a lack of accuracy of the prediction model, but most likely the generally higher cost in Switzerland as well as the difficulties to

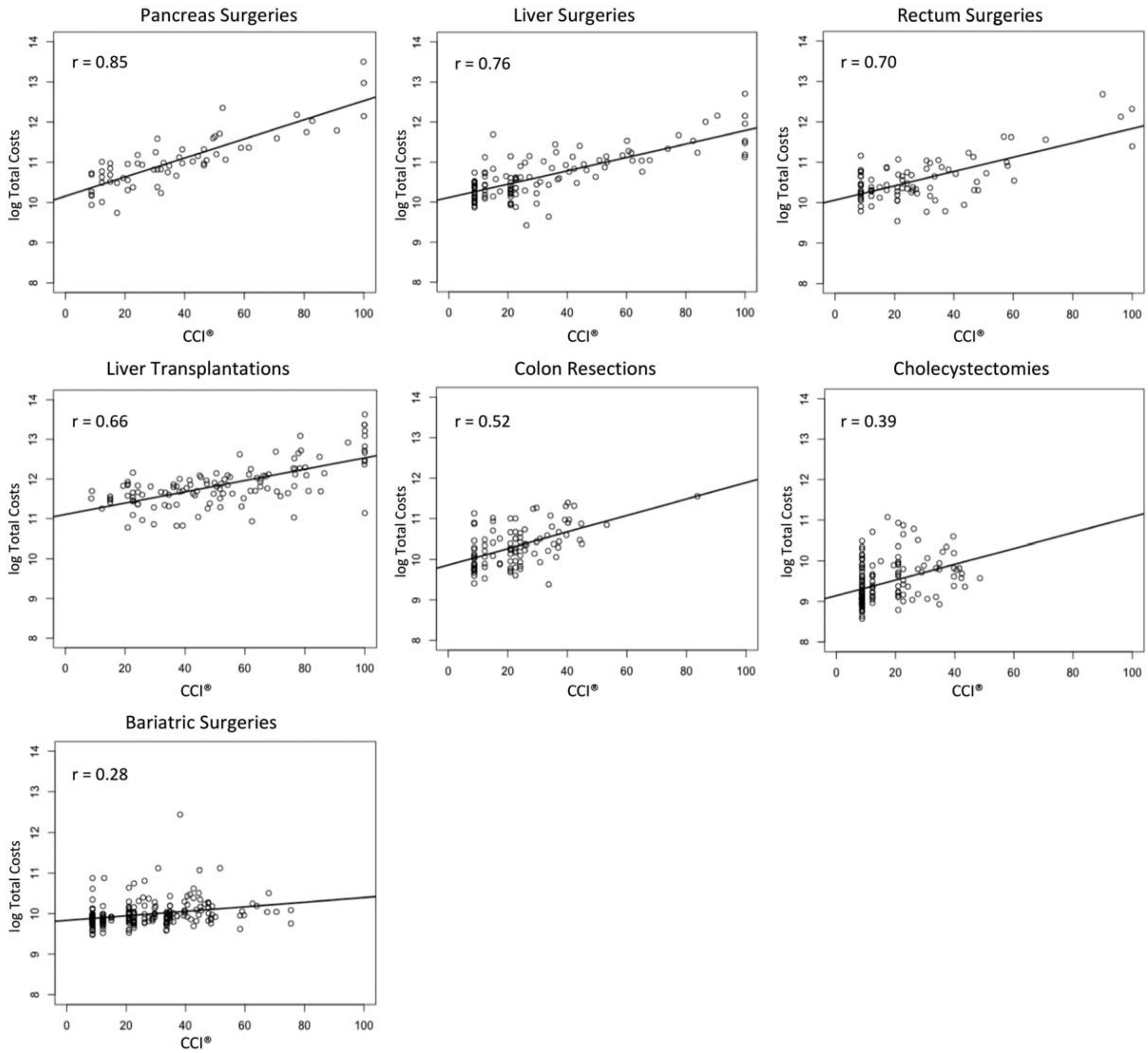

FIGURE 2. Correlation of CCI® and log of total costs of each of the 7 surgical groups from Zurich 3 months postoperatively. Pearson correlation coefficient (r_{pears}).

completely collect cost. After recalibration of the prediction model for the international data by updating the intercept by -1.3, the results ended up on the ideal line (Figs. 3E, F). This recalibrated model is added to our online calculator for cost calculation outside Switzerland.

Accepting CCI® as an adequate marker of cost, we may see at least 2 highly relevant implications, first in the diagnosis-related group (DRG) reimbursement systems and second in benchmarking surgical quality. In a medical system with DRG or similar cost reimbursements, a standardized ''price'' is determined for each procedure by the average cost of the intervention. However, the calculation of patients' individual CCI® would be a more logical and transparent way for reimbursement of specific surgical cases. Some may argue that such practice only promotes higher reimbursements to hospitals with poorer surgical quality. Indeed, such reimbursement system would only work, when the centers' outcome is equally assessed to a validated level of quality (eg, benchmark). In this context, verified good surgical outcome would represent high surgical quality instead of the commonly equated center's case load. Of note, surgical outcome improvement analogue the economic-based concept of benchmarking (improving products/processes by comparison with the best on the market) has caught increasing interest in the surgical community in the past few years.[12,19–21]

There are a number of limitations in this inaugural study. First, we only evaluated 7 abdominal procedure groups. How the CCI® may inform on cost in other surgical fields, such as orthopedic, cardiovascular, or neurosurgical procedures, needs to be further investigated. Second, we did not extensively look at additional predictors of cost, which may also have an impact. This was done consciously to prevent creating a complicated, cumbersome formula, which may likewise not gain acceptance in the surgical community. Age is an objective surrogate marker of comorbidities and was highly additive to the CCI® in the prediction model. Third, while a 3-month follow-up is adequate for most abdominal procedures, it is too short for LT, which should cover 1 year, as documented in a recent benchmark study.[19] Fourth, our model may underestimate cost of treatment in some extremely severe diseases, such as necrotizing pancreatitis requiring multiple second looks/necrosectomies. It was suggested to count planned successive laparotomies only once as grade 3b complication. This should be reconsidered when using

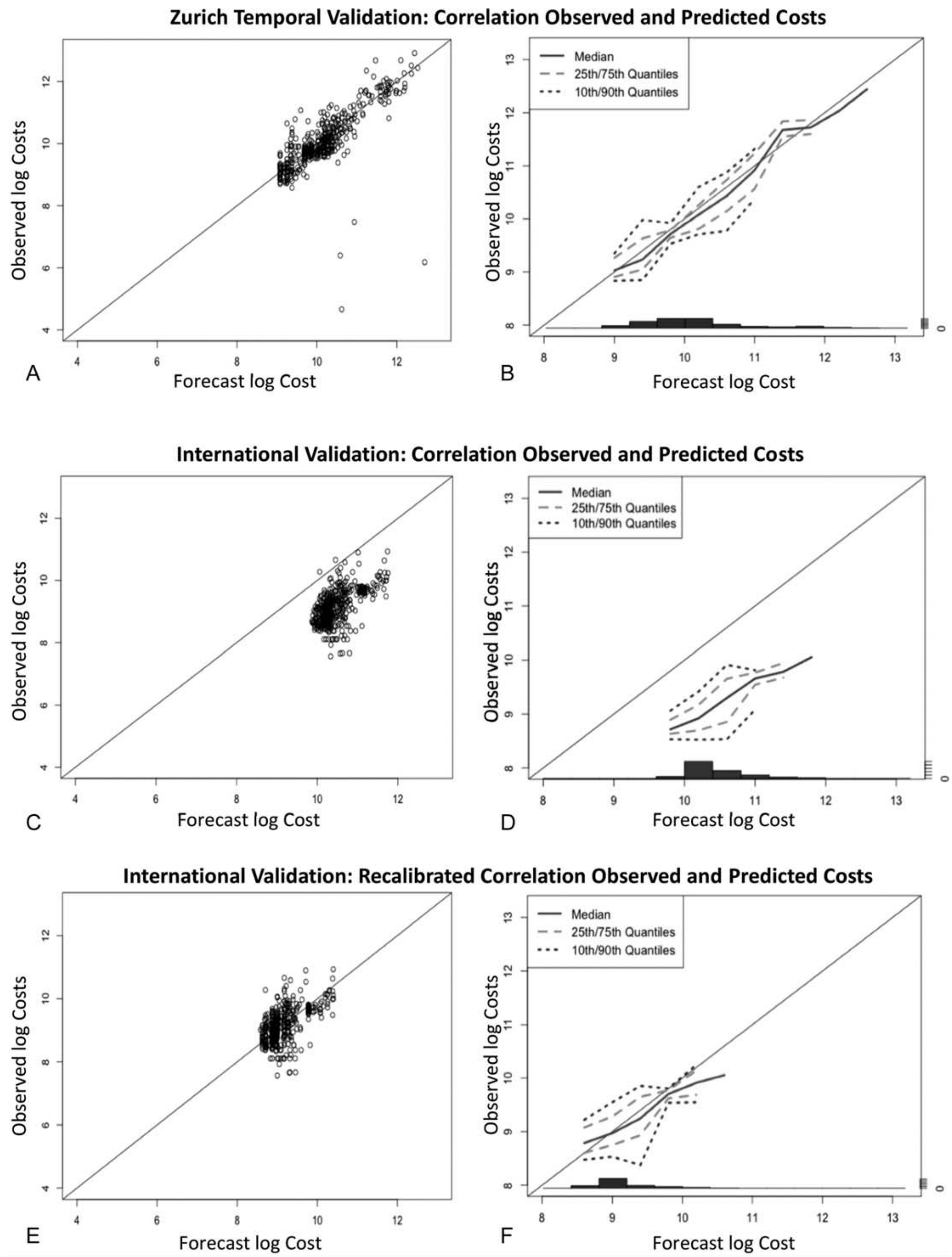

FIGURE 3. (A) Correlation of observed and predicted log costs of the Zurich validation data. (Natural log). (B) Conditional quantile plot showing the correlation of observed and predicted log costs of the Zurich validation data, presented as median and the interquartile ranges. The blue columns indicate the number of patients within the range (sections of 0.4) of predicted costs. (Natural log). (C) Correlation of observed and predicted log costs of the international validation data. The shown mean deviation of log 1.3 of observed to predicted costs corresponds to a 27.8% overestimation of costs. (Natural log). (D) Conditional quantile plot showing the correlation of observed and predicted log costs of the international validation data. The shown mean deviation of log 1.3 of observed to predicted costs corresponds to a mean of 27.8% overestimation of costs. The blue columns indicate the number of patients within the range (sections of 0.4) of predicted costs. (Natural log). (E) Correlation of observed and predicted log cost after recalibration of the prediction model by updating the intercept by -1.3. (F) Conditional quantile plot showing the correlation of observed and predicted log costs of the international validation data after recalibration of the prediction model by updating the intercept by -1.3.

CCI® for cost assessment. Finally, the study focused exclusively on direct cost, ignoring economic implications such as time out to work or events leading to permanent invalidity. Obviously, this must be assessed separately.

In summary, this study suggests that cumulative cost of a procedure strongly correlate with overall postoperative morbidity, as quantified by the CCI®. This novel approach appears to be independent of the health care system and cost assessment and is therefore, internationally applicable. It may guide optimal surgical performance in the future. Such cost assessment on the basis of cumulative morbidity may open the door for more objective surgical quality assessment as well as outcome improvement across the world.

ACKNOWLEDGMENTS

The authors thank J. Braun (Epidemiology, Biostatistics and Prevention Institute, Zurich, Switzerland) for her statistical support, as well as F. Rössler, Ch. Kümmerli, T. Reese, and P. Sanchez-Velazquez (Department of Surgery and Transplantation, University Hospital Zurich, Switzerland); B. Miguel-Huguet (Department of General and Digestive Surgery), R. Moreno-Fuentes (Economic Department), and P. Fernandez (Quality Control Unit) of Bellvitge University Hospital and IDIBELL, Spain; Joan Sánchez, Anna Sabater, and Joan Faner (Hospital Clínic, Barcelona) for their highly valued assistance in data collection.

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DISCUSSANTS

Han-Kwang Yang (Seoul, Korea):

I would like to start by thanking the authors for this interesting paper.

I have the following questions:

First, it is well known that surgical procedures, which are followed by postoperative complications, are more cost-intensive than cases without any complications. What is the benefit of using CCI® for cost-correlation, instead of overall complication rate, major complication rate or even specific potentially cost-intensive complications? With respects to the trademark that is put on the CCI®, you should justify why you chose to use this parameter over another one for your analysis.

Second, the authors conclude that this model might "guide optimal surgical performance," but in respect of the previous concern, there might be a problem. If the CCI® is used as a marker to compare costs within two or more hospitals, then this would be a high incentive to only accept low-risk patients. So, a cost model that also considers the fact that some surgical cases can only be carried out with a certain higher medical and economic risk (independent from the quality of medical care) is needed.

I would like to thank the authors for this very interesting manuscript and the ESA for the privilege of being the first discussant of this paper.

Response From Roxane D. Staiger (Zurich, Switzerland):

Thank you, Prof. Yang, for these interesting questions. So far, what we knew before conducting this study was the fact that there is a correlation between cost and the most severe complications that occur in a postoperative course. If we want to go further and actually predict cost, we need to include every single complication that has occurred because each of them has an impact on the overall cost. As far as we know, the CCI® is the only index that can include every complication that has occurred. Now, if we were to only focus on the most severe complications, the ones with a Clavien-Dindo score of 3a and above, then we would disregard the cost of lower complications as well as those of additional severe complications. Therefore, the predicted cost would be underestimated.

Regarding your second question, you mentioned the fear of risk adverse behavior, when we start to compare outcome using either the CCI® or cost. Of course, whenever we have a grading system, this creates a certain amount of discomfort for us surgeons because it mirrors our imperfections. When we start comparing outcomes, we always need to consider the complexity of the patients involved and, of course, make any necessary adjustments.

Antonio D. Pinna (Bologna, Italy):

Thank you for this very nice presentation and interesting data. Was the purpose of your study to predict cost immediately following a complication? I foresee a fantastic opportunity to use this approach to recalculate the cost of other procedures on a benchmark basis. For example, it could be used to recalculate the average actual cost of a liver transplant or liver resection. Congratulations again on your thought-provoking study.

Response From Roxane D. Staiger (Zurich, Switzerland):

Thank you, Prof. Pinna, for your kind comment. We did not focus on predicting or assessing the cost immediately following the complication. For us, the interesting timeframe is the first three months after surgery because that is when most complications occur. Therefore, rather than predicting the cost immediately after a complication arises, we would recommend to calculate the entire costs three months following the surgery.

With regard to your second point, our ability to calculate cost now opens up many new possibilities, which we can take advantage of. You mentioned benchmarking, which is indeed an option. Also, in certain reimbursement systems, we could monitor whether the amount of money we received actually matches the amount the patient cost us. So, we will need to explore now the many options that this tool gives us.

Giovanni Zaninotto (London, United Kingdom):

Thank you very much for your clear presentation. I have the following three questions for you:

First, the costs were calculated and validated in high-volume academic centers. Did you ever apply the calculation of the costs to normal hospitals?

Second, the prediction of the costs is better for complex operations than for simple ones, such as a cholecystectomy. What if we were to apply this type of cost calculation to other types of operations, such as appendectomies or hernia repairs, which are the most common?

Third, the Cost Complexity Index has only been validated in abdominal operations. Do you have any idea whether this could be applicable to extra abdominal operations?

Response From Roxane D. Staiger (Zurich, Switzerland):

Thank you, Prof. Zaninotto, for your important questions.

Your first question addresses the issue how our model may apply to non-academic institutions. While smaller institutions have consistently lower costs than large centers due to less infrastructure, we would expect our model to be valid, but this needs, however, some additional validation.

Your second question is whether the model may apply to other procedures, particularly simple ones, such as appendectomy. We would like to make 2 points. First, we believe that the principle may apply to most procedures, but each would need, again, validation. Next, perhaps we did not emphasize enough the difference between prediction and correlation. The model is in fact as accurate for small as it is for complex procedures. The correlation, however, was stronger for more demanding procedures, but these correlations were just basic statistics before we performed the prediction modelling.

Your third point about extra-abdominal procedures needs further studies, but we would anticipate that the principle would remain valid.

Final comment From Pierre-Alain Clavien (Zurich, Switzerland):

I would just like to make one last comment and congratulate Roxane for her great presentation. Today, we are overwhelmed by administrative duties as well as figures on cost, reimbursements or DRGs. These figures, which are difficult for us to grasp, are typically used to request a tighter budget. The incentive behind the current study was to develop a simple tool, which can predict costs and estimate the real costs of specific cases. The proposed simple formula, based on post-operative complications (CCI®) and the age of the patients, may be seen as a new language to challenge our administration or external payers, who continuously argue against paying for complications. While no one would support a system rewarding poor care, the real cost of our work must be honored. Thus, in order to apply such a tool in our practice, we must first demonstrate that the quality of care is high or at least adequate. There may be several ways to measure the quality of care. For example, benchmark cut-offs in low risk patients have been established for a number of oncological and surgical endpoints, including complications, and may serve as references to judge the quality of care at specific centers. If the center qualifies for quality (values below the cut-offs), the proposed formula can be used as a valid tool to assess costs for any group of patients and prevent risk avoidance policies to maximize good results. In order to remain plausible partners in healthcare delivery, we must enter the world of the health economy. Thank you for authorizing us to present our study to this very prestigious group of surgeons.